

Final Report on

TRANSITION IN SUPERSONIC FLOWS WITH CORNERS

Submitted to

AERO-THERMODYNAMICS BRANCH
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by

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ABSTRACT

It is proposed to investigate the effect of sudden change in the slope of the surface on the stability and transition onset point in supersonic and hypersonic boundary layers. Since we can not use the linear stability theory in flows where there are discontinuities we have to solve the full Navier-Stokes equations to determine the amplification of the disturbances across the oblique shock which exists at the corner. We will use the Navier-Stokes code which was developed by Dr. Harold Atkins in the aerodynamic and acoustic methods branch. The code is developed using the higher order ENO scheme and is currently set up for two-dimensional flows.

In the first year of our investigation, we will investigate the evolution of small amplitude two-dimensional disturbances and determine the N-factors for the most amplified disturbances. We will perform the analysis for the parameter similar to X-31 model and flight experiment conditions. From these computation we will infer what is the maximum amplification rate possible in quite environments without any tripping devices. In the second part of the investigation, we will perform nonlinear computations to determine what is the minimum amplitudes necessary to cause the transition at a designed location. In the third part, we have to determine what kind of trip devices necessary to excite the required disturbances.

The principal investigator of this project is Dr. P. Balakumar, Associate Professor of Department of Aerospace Engineering, Old Dominion University. We will actively collaborate with research scientists in the Aero-Thermodynamics Branch at NASA/Langley Research Center. A half-time graduate student will also participate in the project.

1. MOTIVATION

1.1 Introduction

The transition process in incompressible and compressible flat-plate and axisymmetric boundary layers can be easily analyzed using linear stability and PSE methods. The transition onset point can be predicted using the N-factor method. In boundary layer flows with discontinuities, the linear stability theory and the PSE method cease to be valid and we have to solve the full Navier-Stokes equations to find the evolution of the disturbances. The motivation of this work

is to determine the flow conditions in front of the inlet to the propulsion system in the X-31 flight vehicle in the flight conditions without any tripping devices and also to determine what is the efficient way to cause the transition before the inlet. This investigation also will improve our understanding of the effects of corner shocks which exist in most of the hypersonic and supersonic vehicles on the transition onset point.

In this work we will investigate the stability and the transition onset point in the supersonic and hypersonic flows over wedge shaped geometries as shown in figure 1. In the flat regions AB and BC classical linear stability theory and the PSE method can be applied. The evolution of the disturbance across the corner can only be determined by solving the full Navier-Stokes equations.

The solution of the full Navier-Stokes equations to determine the evolution of the instability waves requires higher order accurate numerical scheme. In this problem we also have to capture the oblique shock and its oscillations accurately. We will employ the higher order accurate ENO scheme and higher order Runge-Kutta time marching scheme in the computations.

1.2 Objectives

The objective of this investigation is to determine the evolution of the linear disturbances and the N-factors for the most amplified disturbances in supersonic and hypersonic flow over wedge shaped geometries. The second objective is to perform nonlinear computations to determine what is the minimum amplitudes necessary to cause transition at a designated location. The third objective is to identify efficient tripping devices which will generate these disturbances with minimum drag force.

2. DESCRIPTION OF PROPOSED COMPUTATIONS

We will solve the full unsteady Navier-Stokes equations to determine the N-factors for the most amplified disturbances for supersonic and hypersonic flows over wedge shaped geometries as shown in figure 1. We will use higher order ENO scheme to compute the spatial derivatives and use the Runge-Kutta time integration method to compute the time accurate solution. We will first solve for the steady solution over the prescribed geometry and then perturb the flow at an initial location (figure 2) to study the evolution of disturbances downstream.

We will perform the computations for the parameters similar to X-31 model and flight experiment conditions.

Most of the computations will be done on the SGI machines available in the Department of Aerospace Engineering at Old Dominion University.

3. TIME PERIOD AND GOALS

In the first year, we will investigate the evolution of small amplitudes two-dimensional disturbances and determine the N-factors for the most amplified disturbances. The goal is to find what is the maximum amplification possible in quiet environments without any tripping devices.

In the second year, we will perform nonlinear computations to determine what is the minimum amplitudes necessary to cause the transition at a designated location.

4. PERSONNEL

The principal investigator of this project is Dr. P. Balakumar, Associate Professor of Department of Aerospace Engineering, Old Dominion University. We will actively collaborate with research scientists in the Aero-Thermodynamics Branch at NASA/Langley Research Center. A half-time graduate student will also participate in the project.